Journal of Vestibular Research 12 (2002/2003) 191–200
IOS Press

Lack of gender difference in motion sickness induced by vestibular Coriolis cross-coupling

Bob Cheung* and Kevin Hofer
Defence Research and Development Canada, Department of National Defence, Toronto, Canada

Received 9 October 2002
Accepted 14 March 2003

Abstract. It has been reported that females are more susceptible to motion sickness than males. Supporting evidence is primarily based on retrospective survey questionnaires and self-reporting. We investigated if there is a gender difference in motion sickness susceptibility using objective and subjective measurements under controlled laboratory conditions. Thirty healthy subjects (14 males and 16 females) between the ages of 18–46 years were exposed to Coriolis cross-coupling stimulation, induced by 120°/s yaw rotation and a simultaneous 45° pitch forward head movement in the sagittal plane every 12 seconds. Cutaneous forearm and calf blood flow, blood pressure, and heart rate were monitored. Graybiel's diagnostic criteria were used to assess sickness susceptibility before and after motion exposure. Golding and Kerguelen's scale was used to assess the severity of symptoms during motion exposure. A significant ($p < 0.01$) increase of forearm and calf blood flow during cross-coupling stimulation was observed in both sexes. However, the subjective symptoms rating and blood flow measurements indicate that there was no significant difference between male and female subjects. Our data also suggests that females may be more inclined to admit discomfort as indicated by their responses to a survey of motion sickness history prior to the experiment.

Keywords: Coriolis, gender, motion sickness

1. Introduction

Motion sickness can be defined as the maladaptive response to real or apparent motion. Throughout the history of motion sickness reviews [4,26,30,33,41], it has been suggested that females are more susceptible to motion sickness than males, based on evidence collected in different motion environments. For example, it was reported that females are more susceptible to seasickness [1,6,14,20,21,27,39]; to airsickness [22]; to short-haul flights [40]; and to motion sickness on the train [18]. In addition, women rate themselves as more likely to suffer from motion sickness on carnival devices and while performing gymnastics [23,30]. Typically, women reported a higher incidence of vomiting and more severe symptoms of motion sickness. In the laboratory, male college students reported less experience with motion sickness than female students ($p < 0.02$) when they responded to questionnaires regarding past history of motion sickness [5]. Using an automated scoring system, Kennedy et al. [19] reported that sickness rates in military flight simulators were higher in females than in males. A recent survey by Dobie et al. [8] concluded that higher motion sickness susceptibility among females does not appear to vary significantly with age and cannot be attributed to differences in exposure to motion or physical activity. In contrast, Levy and Rapaport [24] reported that there was no difference in seasickness susceptibility between males and females during an anti-motion sickness drug study aboard large sailing yachts. Similarly, Turner [38] found no significant gender difference in motion sickness ratings or incidence of experiencing

*Corresponding author: Dr. Bob Cheung, Project Leader for Spatial Disorientation Countermeasures, Defence Research and Development Canada – Toronto, Department of National Defence, P O Box 2000, 1133 Sheppard Ave W, Toronto, Ontario, Canada, M3M 3B9. Tel.: +416 635 2053; Fax: +416 635 2204; E-mail: bob.cheung@drdc-rddc.gc.ca.

ISSN 0957-4271/02/03/$8.00 © 2002/2003 – IOS Press. All rights reserved

different symptoms during coach journeys. Although females tend to report more symptoms in visually induced sickness than males, no significant main effects for gender difference [17] and no significant differences in symptom severity between genders [28] were found.

The cardinal signs and symptoms of motion sickness are cold sweating, pallor, salivation, drowsiness, nausea and vomiting. These signs and symptoms also serve as indicators of changes in the autonomic nervous system. Therefore, it is reasonable to suspect that there are measurable physiological changes that accompany motion sickness. However, previous efforts to identify a systematic relationship between motion sickness blood pressure and heart rate, and respiration, have presented conflicting results. For example, subjects exposed to Z (spinal) axis recumbent rotation about the horizontal axis [11], visual-vestibular sudden stop test [12], and during vestibular Coriolis cross coupled stimulation [2, 36] did not show between or within subject relationships, between heart rate, blood pressure, respiration, skin temperature and subjective symptoms of motion sickness. On the contrary, Cowings et al. [7] reported that biofeedback control of heart rate, blood pressure and body temperature decreased the severity of motion sickness experienced within subjects during vestibular Coriolis cross coupling. Provocation of nausea accompanied by an increase in cutaneous forearm and calf blood flow (BF) without significant changes in heart rate and blood pressure appears to show relatively consistent findings during acute motion sickness. The increase in cutaneous blood flow was demonstrated by venous occlusion plethysmography [34,36,37] and Laser Doppler flowmetry [2,3].

With the exception of the studies by Levy and Rapaport [24] and Turner [38], the findings that females are more susceptible to motion sickness than males are essentially consistent when large samples are employed and commercial transportation is involved. All of these studies employed survey questionnaires and self-report of motion sickness symptoms while exposed to a provocative environment or responding to surveys on past history of motion sickness. It is possible that the gender difference reported in motion sickness susceptibility is attributed by a difference in reporting sickness symptoms and discomfort between male and female subjects. The objective of this study is to investigate if there is a gender difference in Coriolis cross coupling induced sickness by comparing subjective symptoms ratings and cutaneous blood flow changes before, during and after provocative motion exposure under controlled laboratory conditions.

2. Materials and methods

2.1. Subjects

Thirty healthy subjects, 14 males (22 to 46 years, mean age = 25.38 ± 5.81 years) and 16 females (18–36 years, mean age = 24.12 ± 5.05 years) participated in the studies. Recruitment was from local universities and personnel from the laboratory, comprised of undergraduates, graduate students and laboratory assistants. Approval for this study was obtained from the Defence Research and Development Canada – Toronto (DRDC-Toronto, formerly the Defence and Civil Institute of Environmental Medicine) Human Ethics Committee. Subjects obtained medical approval to participate and gave informed consent. They had no known history of oculomotor or vestibular disorders, and they had neither spontaneous nystagmus, nor Romberg's sign with eyes opened or closed. The subjects were instructed to abstain from alcohol, tobacco, over-the-counter antihistamines and other cold remedies for at least 24 hours prior to the experiment. All except two male subjects had no previous experience with Coriolis stimulation. Each of the subjects also responded to a survey questionnaire on their motion sickness history [10] prior to motion exposure.

2.2. Apparatus

The motion device is a rotating platform (1.8 m in radius) driven by a motor with maximum torque of 12.2 (Newton-metre) to produce a maximum angular velocity of up to 240°/s. For this study the angular velocity of yaw rotation was 120°/s. Subjects were seated at the centre of rotation. A motor-driven headrest controlled by a timer was used to guide and maintain the subject's head in a forward and downward movement through an angle of 45° within 2 seconds in the sagittal plane. The simultaneous periodic pitching of the head forward and passive yaw rotation at constant velocity produces an illusion of rolling and yawing in the opposite direction, and notably symptoms of motion sickness. Figure 1 illustrates the rotating platform and the recording apparatus.

2.3. Subjective symptom ratings and indication of anxiety

Before and after each trial, Graybiel's diagnostic criteria [13] were used to quantify the subjective symptoms and severity of sickness. The diagnostic crite-

104-05658/

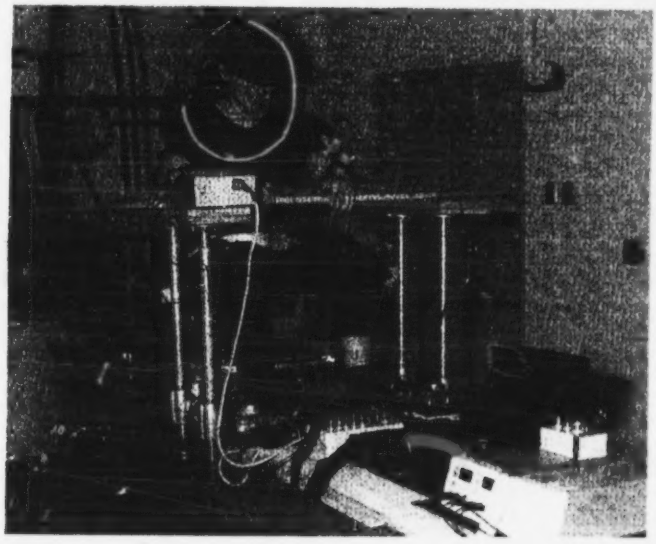

Fig. 1. A photograph of the DRDC-Toronto motion platform with the subject seated at the centre of the axis of rotation and a mechanical device to assist in making the head movements.

ria are contained in a checklist for scoring the severity of motion sickness, using a variety of signs and symptoms such as epigastric awareness, epigastric discomfort, nausea, vomiting/retching, and other symptoms such as subjective warmth, dizziness, headache, drowsiness, cold sweating, pallor and increased salivation. Points can be accumulated both by exhibiting a greater variety of symptoms or by exhibiting more severe symptoms. The principal investigator, who has many years of experience in evaluating motion sickness, evaluated the signs of cold sweating and pallor. The subjects reported their symptoms of motion sickness based on their current state of well being. During the exposure to cross-coupling stimulation, subjects rated the severity of motion sickness symptoms after each head movement on the following scale: 1 = no symptoms; 2 = any symptoms, however slight; 3 = mild symptoms, e.g. stomach awareness but no nausea; 4 = mild nausea; 5 = mild to moderate nausea; 6 = moderate nausea but can continue; 7 = moderate nausea, want to stop [9]. The subjects were instructed that they did not have to follow the scale in the written sequence, but rather to pair symptoms they experienced at a particular instant with a specific level on the scale (i.e. they could change from a rating of 4 to a rating of 2 to a rating of 5). This scale was used primarily to assist the subjects to recognise the end point of the trial, and to evaluate the mean sickness level reached during the trial without giving a lengthy description of the symptoms. Since the individual's level of anxiety during nauseogenic and stressful stimulation could affect their physiological response, the State-Anxiety scale [35] was used as an indicator of change in transitory anxiety experienced by the subjects. The State-Anxiety scale was also administered before and after each trial.

2.4. *Physiological measurements*

Continuous forearm and calf cutaneous BF changes were monitored using the Perimed Periflux 5001 Laser Doppler system in combination with two Perimed 413 integrating probes (Perimed Inc., Stockholm, Sweden). With the subject's hand resting on a flat surface with palm down, the integrating probe was positioned on the lateral surface of the left forearm in the region of the largest circumference. A second integrating probe was positioned on the dorsal surface of the left calf, left of the midline in the region of largest circumference. Ambient temperature in the laboratory was maintained between 22 and 24°C. Blood pressure and heart rate were monitored using the Portapres Model-2 (TNO, TPD Biomedical Instrumentation Amsterdam, The Netherlands) to ensure that the increase in forearm and calf blood flow was not accompanied by changes in BP and HR as reported previously [2,36]. The Portapres is

a non-invasive continuous finger blood pressure measurement and recording system, which employs the volume–clamp method to measure BP in the finger and can be corrected to heart or head level. The diameter of an artery under an inflatable cuff wrap around the finger is kept constant (clamped) despite the changes in arterial pressure during each heartbeat. Infrared photoplethysmography detects changes in the arterial diameter. These changes are opposed by a fast pressure servo controller, which alters the pressure in the inflatable air bladder. The BeatScope software (TNO TPD Biomedical Instrumentation) enables the beat-to-beat analysis of the finger arterial pressure signal and also enables the usage of waveform filtering. Base on the Modelflow cardiac output method [43], BeatScope computes the instant of upstroke, systolic, diastolic and mean blood pressure, heart rate, stroke volume and cardiac output for every heart beat.

2.5. Procedure

Motion conditions consisted of the following: condition 1 - at rest, condition 2–120°/s yaw rotation, condition 3–120°/s yaw rotation and pitching head movements (i.e., Coriolis cross-coupling stimulation), condition 4–120°/s yaw rotation, and condition 5 – at rest. The experimental protocol is summarised in Fig. 2. It has been shown that rotation of the seated subject about its spinal (yaw) axis results in a radial acceleration gradient impeding venous return, thereby representing a cardiovascular stress [42]. Conditions 2 and 4 were included to verify that yaw rotation alone (at 120°/s) did not affect blood flow changes. Each head movement consisted of pitching the head forward and downward in the sagittal plane to 45° from upright, maintaining this position for 12 seconds, followed by a return head movement to upright position, maintaining the head's position for another 12 seconds, before the next pitching movement. The initiation of each head movement was timed according to an interval set by a metronome. At the end of each head movement the subject was instructed to rate their symptoms according to Golding and Kerguelen's scale [9] and to report the rating verbally by a numerical score only. The end-point for each trial is either reaching a rating of 7 on the scale, or 15 minutes of Coriolis cross-coupling stimulation, whichever comes first. Rotation at 120°/s was continued for another 3 minutes after head movements were stopped unless subjects chose to abort. The number of head movements made during the Coriolis cross-coupling stimulation also serves as an objective measurement to compare the susceptibility (or tolerance to the Coriolis stress) between males and females. The utility of this approach in evaluating motion sickness susceptibility or Coriolis stress endured by the subjects in reaching a predetermined level of symptomatology was shown by Miller and Graybiel [25] where Coriolis stress is directly proportional to the number of head movements made, provided the test is conducted at a fixed rotational velocity. Cumulative data from our laboratory over the last four years using identical profile as the current study suggests that 63 out of 87 subjects (72.4%) were able to withstand more than 5 minutes of stimulation or more than approximately 20 head movements.

Actual exposure techniques and personal history questionnaires has long been recognized as the preferred methods of assessment [31]. We employed the "Actual exposure technique" in this study. As the name implies, actual exposure involves exposing the subject to a motion stimulus and then grading their susceptibility, either in terms of their symptomatology (e.g. Graybiel Diagnostic Criteria) after a controlled exposure or with regard to the amount of stimulation they sustain (e.g. number of head movements tolerated) prior to displaying some predetermined criterion of motion sickness (e.g. definite nausea). Similar to the recovery rate following Coriolis stimulation, the development of motion sickness is subject-specific. For example, some subjects recovered quickly (their symptoms subside) as soon as the head remained stationary even for short period. These issues relate to the receptivity and adaptability of the individuals, which require separate investigation. We used the Golding and Kerguelen scale as an indication when the subjects reached their end point.

3. Results

3.1. Survey of past history of motion sickness

Past history of motion sickness is a measurement of the individual's susceptibility based on previous experiences. Using the non-parametric analysis, Mann-Whitney U Test, our data revealed that in recalling susceptibility to motion sickness as a child and during the last twelve years, women rated themselves more susceptible to men in both age level: childhood ($U = 61.5$, $p = 0.020872$) last 12 years ($U = 47.5$, $p = 0.003469$). However, in recalling the frequency of vomiting episodes as a result of motion sickness in either age level, no gender differences were found.

Condition	1 At rest	2 Yaw rotation	3 Yaw rotation & head movements	4 Yaw rotation	5 At rest
Time interval	t = 3min	t = 3min	t ≤ 15min	t = 3min	t = 3min

Time ⟶

Fig. 2. Experimental procedure illustrating the motion conditions with time: (1) at rest, sitting upright (2) yaw rotation at 120°/s (3) yaw rotation at 120°/s with pitching head movement every 12 seconds, and reporting symptoms of nausea according to the Golding's scale at the end of each head movement. The end point for the trial is reaching a rating of "7" on the Golding's scale or 15 minutes, whichever came first. Condition (4) is identical to (2), and condition (5) is identical to condition (1).

3.2. Subjective symptoms of motion sickness reported and number of head movements tolerated during Coriolis stimulation

None of the subjects reported significant symptoms of motion sickness during conditions 1 (at rest) and conditions 2 (yaw rotation only). All susceptible subjects reported symptoms of motion sickness during condition 3 until they reached the end point of moderate nausea. Two female and one male subjects completed 15 minutes of Coriolis stimulation without reaching the end point of moderate nausea (7 on the rating scale). The highest score reached by the two females were 3 and 4 respectively and the highest score reached by the male subject was 4. The mean sickness scores for all male and female subjects were 4.06 ± 0.47 and 3.94 ± 0.44 ($p = 0.23$). The mean total number of head movements attained by the male and female subjects was 17.16 ± 3.12 and 21.56 ± 3.87 respectively, not statistically significant ($p = 0.23$, power estimate is 0.72 at an α level of 0.01). Since subjects exhibited different rate of recovery following Coriolis stimulation throughout conditions 4 and 5, we did not compare the signs and symptoms exhibited during these two conditions with the others.

3.3. Subjective symptom measurements before and after motion exposure

Friedman non-parametric ANOVA of ranks was employed to evaluate the subjective responses to motion sickness before and after the exposure to Coriolis cross-coupling stimulation. The results obtained from the evaluation of motion sickness based on the Graybiel diagnostic criteria and state anxiety were similar. Subjects displayed more outward signs of motion sickness (pallor and cold sweating as observed by the experimenter), reported more symptoms (Fig. 3) and were more anxious (Fig. 4) after the trial. In all cases, significant differences were found in the respective evaluations before and after cross-coupling stimulations ($\chi^2(1, 30) = 30$, $p < 0.01$). However, there was no significant gender differences in the anxiety and severity of motion sickness symptoms reported after exposure to Coriolis cross-coupling stimulation. Similar results were found using the Wilcoxon signed ranked tests, significant contrasts were found between conditions before and after Coriolis cross-coupling stimulation for each of the above measurements ($p < 0.01$).

3.4. Cutaneous blood flow

Figure 5 demonstrates typical raw traces of forearm and calf skin blood flow changes during a complete trial. Similar to previous findings [3,4], qualitatively, when the subject was stationary or under yaw rotation alone blood flow changes were not apparent. However, a simultaneous increase in rhythmic blood flow fluctuation in the forearm and calf was observed. All "susceptible subjects" displayed a distinct shift of the rhythmic blood flow as indicated by the increase in perfusion units. The two female and one male subject who demonstrated resistance to the Coriolis stimulus lacked an identifiable forearm and calf blood flow increase. Prior to data analysis, artefacts from raw BF from each trial were reviewed and excluded from further analyses. Artefacts constituted less than 1% of the recorded data. BF data was analysed using Perimed's Perisoft for Windows (Perimed Inc., Stockholm, Sweden, version 1.19.2). Since we were interested in comparing blood flow increases before (condition 2) and during Coriolis stimulation (condition 3) where significant symptoms of motion sickness were reported, blood flow changes between condition 2 and 3 were compared. We did not compare with condition 4 (yaw rotation after Coriolis stimulation) since the recovery

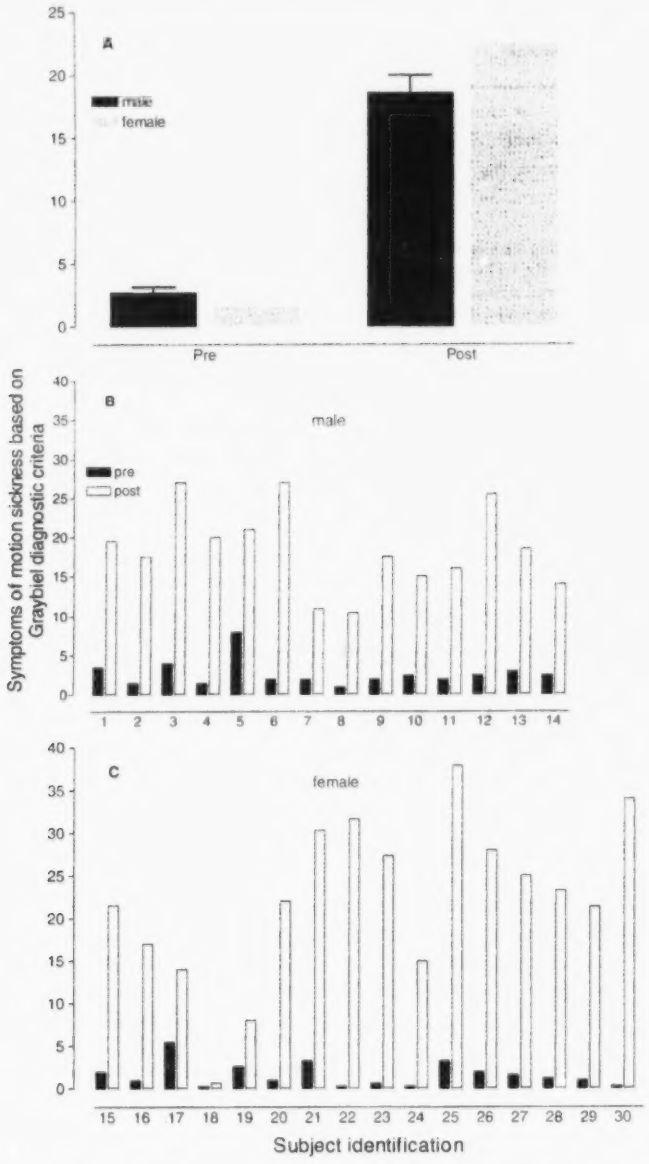

Fig. 3. Evaluation of symptoms of motion sickness before and after the exposure to Coriolis cross-coupling in the male and female groups (A) and the distributions showing the individual severity of motion sickness symptom among males (B) and females (C) based on the Graybiel diagnostic criteria. Error bars represent standard error of the mean, SEM.

rate of each subject varied widely. In condition 3, the time for peak forearm and peak calf blood flow for the Coriolis trial was identified, and 30 seconds before and after each peak was compared with blood flow changes during condition 2 (yaw rotation only). A mixed design ANOVA with gender as the between factor, and BF probe location and motion condition as the repeated factors was employed in the BF analysis. The signifi-

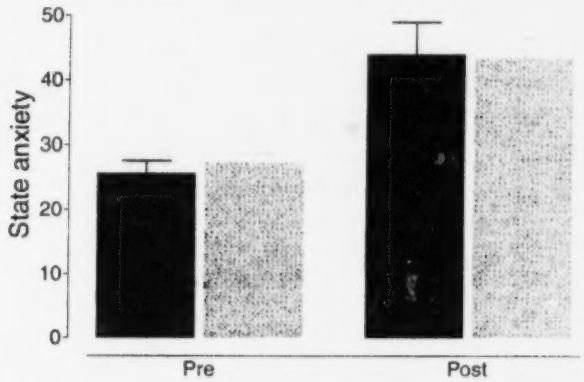

Fig. 4. Evaluation of state anxiety before and after the exposure to Coriolis cross-coupling in the male and female group. Error bars represent standard error of the mean, SEM.

cance level α was set at $\leqslant 0.01$. All post hoc testing was completed using Tukey's HSD post hoc analysis. P-values for factors with more than two levels were adjusted using Greenhouse-Geisser's epsilon correction factor. There was an interaction between probe location and motion condition ($F(1,29) = 8.94$, $p \leqslant 0.01$). Figure 6 illustrates that BF was significantly greater in the forearm than in the calf ($F(1,29) = 90.56$, $p \leqslant 0.01$). Within each location BF increase was significantly greater when subjects reached their end point ($F(1,29) = 24.45$, $p \leqslant 0.01$). However, there was no significant difference (power estimate is 0.73 for $\alpha = 0.01$) between genders. Repeated measures ANOVA performed on the BP and HR data revealed no significant changes throughout the trial.

3.5. Correlations with subjective reports of sickness

Using a Pearson product moment correlation analysis of forearm and calf blood flow during Condition 3 (cross-coupling stimulation) from each trial were compared to the subjective symptoms reported according to the Golding and Kerguelen's scale. The correlations between forearm and calf blood flow and the subjective symptoms were 0.45 ($p < 0.001$) and 0.28 ($p < 0.001$) respectively.

4. Discussion

There have been few motion sickness studies in the laboratory investigating the issue of gender difference. The few empirical experimental studies have been less consistent in showing differences. The sample sizes have been relatively smaller (when compared to survey studies) and based on what appears to be small but significant difference. Our results indicated that there is no gender difference in motion sickness susceptibility as induced by Coriolis cross-coupled stimulation in the laboratory despite greater susceptibility reported by females relative to males on past history of motion sickness. Subjective reports of sickness severity during motion exposure, and observations on signs of motion sickness before and after the provocative stimulus, showed no significant difference. The lack of gender difference in subjective assessment of sickness susceptibility is also reflected by the lack of gender difference in forearm and cutaneous blood flow increases when subjects reached their end point of moderate nausea.

There is no evidence that women show a greater sensory response to nauseogenic motion stimulus [30] and similarly there is no reason to assume that women adapt less readily than men [31]. One of the proposed reasons that females are more susceptible to motion sickness is said to be the influence of the menstrual cycle. Schwab [32] described "... a nurse in the army medical corps who successfully crossed the Atlantic on a small vessel during rough weather without being ill, but who became nauseated and vomited in calm sea of the Mediterranean when her menstrual period began."(p. 636). More recently, during the 1996–1997 "BT Global Challenge Yacht Race", Gresty [15] reported that there was a slight increase in the number of sickness events reported during the premenstrual (Days 25–28) and permenstrual phases (Days 1–5) based on a normalized 28-day cycle. There were fewer complaints of sickness reported before and around the time of ovulation (Days 11–14). However,

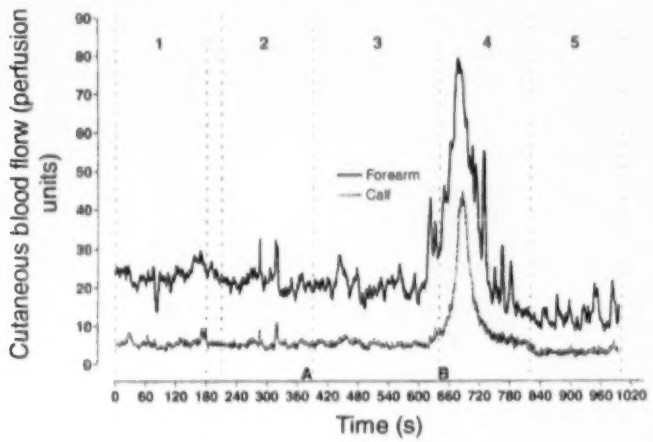

Fig. 5. Raw traces of forearm and calf skin blood flow (PU) recorded from the same subject over the duration of the five conditions in which a rating of "7" was called shortly before peak forearm and calf blood flow was reached. "A" and "B" denotes the beginning and end of Coriolis cross-coupling stimulation respectively. The basic unit of measurement used in the PeriFlux is the Perfusion Unit (PU), which is an arbitrary value equal to the analogue output of 10 mV. This relationship is only valid when the instrument has been calibrated using the PF1000 calibration device. Since the PU is arbitrary it cannot be given any physiological definition such as the actual number of cells flowing through a given volume of tissue during a given time period. In this study measurements of blood flow in response to different motion stimuli were expressed as percentage changes from the calibrated zero.

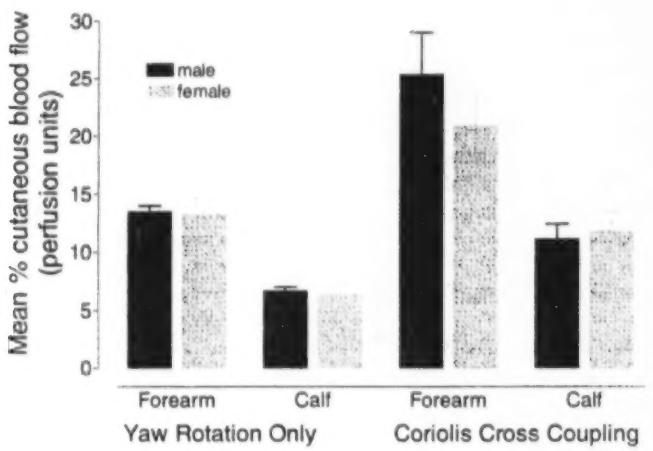

Fig. 6. Mean percentage of cutaneous forearm and calf blood flow of the male and female group during yaw rotation (condition 2) and during Coriolis cross-coupling stimulation (condition 3). Error bars represent SEM.

under controlled laboratory conditions, different phases of the menstrual cycle appear to have no influence on subjective symptoms of motion sickness or on cutaneous blood flow increase in the forearm and calf [3]. In addition, the lack of commonality between the types and levels of hormones that are released during motion sickness and those that are involved in different menstrual phases as reviewed by Cheung et al. [3], appears to support the above finding.

As described previously, questionnaires and self-reports may themselves be subject to a gender bias. Our survey of past history of motion sickness indicated that female considered themselves more susceptible to men during childhood and in the last 12 years. It has been proposed that it might be a reflection of a socialization process in which it is more socially acceptable

for women to report illness than men [16], including motion sickness [17,23]. Therefore, females may be more inclined (or males may be less inclined) to admit discomfort or illness. In addition, females may be more willing to report their feelings of well being than males. Our findings are similar to those of previous study by Park and Hu [28] who reported that there were no significant differences between men and women on the severity of symptoms of motion sickness while viewing an optokinetic drum (visually-induced sickness). However, females reported significantly greater incidence of past history of motion sickness based on subjective questionnaires prior to visual stimulation. These findings suggest that retrospective reports of previous motion sickness susceptibility do not necessary reflect the incidence and severity of motion sickness during an actual motion sickness challenge. It is of interest to note that a study by Pennebaker and Skelton [29] indicated that when subjects were asked to rate their physical symptoms of illness from the past week, month, or year, females reported significantly more symptoms, but when asked to report the degree to which they are currently experiencing, no consistent gender difference was found. Previous reports of higher incidence of motion sickness in females during motion exposure could be due to individual differences in susceptibility. Further investigation is required to explore this possibility.

References

[1] K. Abe, M. Amatomi and S. Kajiyama, Genetical aspects of susceptibility to motion sickness and frost bite, *Hum. Her.* **20** (1970), 507–516.

[2] B. Cheung and K. Hofer, Coriolis-induced cutaneous blood flow increase in the forearm and calf, *Brain Res. Bul.* **54** (2001), 609–618.

[3] B. Cheung, R. Heskin, K. Hofer and M. Gagnon, Menstrual cycle and motion sickness susceptibility, *J. Vest. Res.* **11** (2001), 129–136.

[4] H.I. Chinn and P.K. Smith, Motion sickness, *Pharm. Rev.* **7** (1995), 33–82.

[5] B. Clark and J.D. Stewart, Relationship between motion sickness experience and tests of the perception of rotation in pilots and non-pilots, *Aviat. Space Env. Med.* **44**(4) (1973), 393–396.

[6] C. Cooper, N. Dunbar and M. Mira, Sex and seasickness on the Coral Sea, *Lancet* **50**(9081) (Sep. 1997), 892.

[7] P.S. Cowings, K.H. Naifeh and W.H. Toscano, The stability of individual patterns of autonomic responses to motion sickness stimulation, *Aviat. Space Env. Med.* **61** (1990), 399–405.

[8] T. Dobie, D. McBride, T.Jr. Dobie and J. May, The effects of age and sex on susceptibility to motion sickness, *Aviat. Space Env. Med.* **72**(1) (2001), 13–20.

[9] J.F. Golding and M. Kerguelen, A comparison of the nauseogenic potential of low frequency vertical versus horizontal linear oscillation, *Aviat. Space Env. Med.* **63**(6) (1992), 491–497.

[10] J.F. Golding, Motion sickness susceptibility questionnaire revised and its relationship to other forms of sickness, *Brain Res. Bul.* **47**(5) (1998), 507–516.

[11] A. Graybiel and J.R. Lackner, Comparison of susceptibility to motion sickness during rotation at 30 rpm in the earth-horizontal, 10° head-up, and 10o head-down positions, *Aviat. Space Env. Med.* **48**(1) (1977), 7–11.

[12] A. Graybiel and J.R. Lackner, Evaluation of the relationship between motion sickness symptomatology and blood pressure, heart rate, and body temperature, *Aviat. Space Env. Med.* **51**(3) (1980), 211–214.

[13] A. Graybiel, C.D. Wood, E.F. Miller and D.B. Cramer, Diagnostic criteria for grading the severity of acute motion sickness, *Aerospace Med.* **39**(5) (1968), 453–455.

[14] M.J. Griffin, Sea Sickness. Motion Sickness: Significance in Aerospace Operations and Prophylaxis, in: *AGARD Lecture Series 175, Advisory Group for Aerospace Research and development*, Neuilly-sur-Seine: France, 1991, pp. 7.10–7.20.

[15] E. Grunfeld and M.A. Gresty, Relationship between motion sickness, migraine and menstruation in crew members of a round the world yacht race, *Brain Res. Bul.* **47**(5) (1998), 433–436.

[16] J.H. Hibbard and C.R. Pope, Gender roles, illness orientation and use of medical services, *Soc. Sci. Med.* **17** (1983), 129–137.

[17] M.D. Jokerst, M. Gatto, R. Fazio, P.J. Gianaros, R.M. Stern and K.L. Koch, Effects of gender of subjects and experimenter on susceptibility to motion sickness, *Aviat. Space Env. Med.* **70**(10) (1999), 962–965.

[18] I. Kaplan, Motion sickness in railroads, *Ind. Med. Surg.* **33** (1964), 648–651.

[19] R.S. Kennedy, D.S. Lanham, C.J. Massey and J.M. Drexler, Gender difference in simulator sickness incidence: implications for military virtual reality systems, *Safe J.* **25**(1) (1995), 69–77.

[20] A. Lawther and M.J. Griffin, The motion of a ship at sea and the consequent motion sickness amongst passengers, *Erg.* **29**(4) (1986), 535–552.

[21] A. Lawther and M.J. Griffin, A survey of the occurrence of motion sickness amongst passengers at sea, *Aviat. Space Env. Med.* **59**(5) (1988), 399–406.

[22] L.G. Lederer and G.J. Kidera, Passenger comfort in commercial air travel with reference to motion sickness, *Int. Rec. Med.* **167** (1954), 661.

[23] J.M. Lentz and W.E. Collins, Motion sickness susceptibility and related behavioral characteristics in men and women, *Aviat. Space Env. Med.* **48**(4) (1977), 316–322.

[24] G.D. Levy and M.H. Rapaport, Transderm scopolamine efficacy related to time of application prior to the onset of motion, *Aviat. Space Env. Med.* **56**(6) (1985), 591–593.

[25] E.F. Miller and A. Graybiel, A comparison of five levels of motion sickness severity as the basis for grading susceptibility, *Aerospace Med.* **45** (1974), 602–609.

[26] K.E. Money, Motion sickness, *Phys. Rev.* **50**(1) (1970), 1–39.

[27] J.H. Nieuwenhuijsen, *Experimental investigation of seasickness*, University of Utrecht, 1958, A64890.

[28] A.H. Park and S. Hu, Gender differences in motion sickness history and susceptibility to optokinetic rotation-induced motion sickness, *Aviat. Space Env. Med.* **70**(11) (1999), 1077–1080.

[29] J.W. Pennebaker and J.A. Skelton, Selective monitoring of bodily sensations, *J. Pers. Soc. Psyc.* **41** (1981), 213–223.

[30] J.T. Reason, *An investigation of some factors contributing to individual variation in motion sickness susceptibility*, Flying

Personnel Research Committee Report, London Ministry of Defence (Air Force Department), 1968, No. 1277.
[31] J.T. Reason and J.J. Brand, *Motion sickness*, New York: Academic Press, 1975.
[32] R.S. Schwab, The nonlabyrinthine causes of motion sickness, *Int. Rec. Med.* **167** (1954), 631–637.
[33] K.S. Aparna, Prevalence and correlates of susceptibility to motion sickness, *Acta Geneticae Medicae et Gemellologiae (Roma)*, **46**(2) (1997), 105–121.
[34] B. Sinha, Effect of vestibular Coriolis reaction on respiration and blood-flow changes, *Aerospace Med.* **39** (1968), 837–844.
[35] C.D. Spielberger, *Manual For The State-Trait Anxiety Inventory (Form Y)*, Consulting Psychologists Press, Inc: Palo Alto, California, 1983.
[36] F.A. Sunahara, W.H. Johnson and N.B.G. Taylor, Vestibular stimulation and forearm blood flow, *Cdn. J. Phys. Pharm.* **42** (1964), 199–207.
[37] F.A. Sunahara, J. Farewell, L. Mintz and W.H. Johnson, Pharmacological interventions for motion sickness: cardiovascular effects, *Aviat. Space Env. Med.* **58**(9 Suppl) (1987), A270–276.
[38] M. Turner, A survey of motion sickness in road coaches, in: *Proceedings of the United Kingdom Informal Group Meeting on Human Response to Vibration*, 20–22 September, Farnborough, The Army Personnel Research Establishment, Ministry of Defence, 1995.
[39] M. Turner and M.J. Griffin, Motion sickness incidence during a round-the-world yacht race, *Aviat. Space Env. Med.* **66**(9) (1995), 849–856.
[40] M. Turner, M.J. Griffin and I. Holland, Airsickness and aircraft motion during short-haul flights, *Aviat. Space Env. Med.* **71**(12) (2000), 1181–1189.
[41] D.B. Tyler and P. Bard, Motion sickness, *Phys. Rev.* **29** (1949), 311–369.
[42] C.W. Urschel and W.D. Hood, Cardiovascular effects of rotation in the Z axis, *Aerospace Med.* **37** (1966), 254–256.
[43] K.H. Wesseling, J.R.C. Jansen, J.J. Settels and J.J. Schreuder, Computation of aortic flow from pressure in humans using a nonlinear, three-element model, *J. Appl. Phys.* **74** (1993), 2566–2573.
[44] P.A. Herzberg, Principles of Statistics, John Wiley & Sons, New York, 1983.
[45] G. Keppel, *Design and Analysis: A Researcher's Handbook* (3rd ed.), Prentice Hall, New York, 1991.

Appendix

With a typical recruitment of 14–16 subjects in this type of study there is a potential of making a beta error, or the failure to find a true difference when one does exist. However, it is necessary to note that the area of science under which this study falls is quite different from clinical surveys and social sciences where subject recruitment is large and for which true population means are often available. With this information available it is often easy to estimate power, or the reverse, to estimate the necessary sample size. On the other hand, to the best of our knowledge, there is no population mean for the number of head movements a subject might perform under the conditions of our motion stimulus.

Based on the accumulated data of Coriolis experiments performed in our laboratory over the years, we compared the mean number of head movements made (under the prescribed conditions) in the past studies with the mean number of head movements made in the current study, our best estimate of the hypothesized effect ratio (HES/σ) for the number of head movements made is 0.85. Substituting our value into the power estimation equation provided by Herzberg 1983 or Keppel 1991, δ is 3.24, if we use 3.2 the power estimate is 0.89 at an α level of 0.05 and a power estimate of 0.72 at an α level of 0.01.

Similarly, the a priori power estimates for blood flow measurements are calculated by the following method. Based on pilot studies and past experiments using a similar protocol and with a total of 87 subjects are best estimate of δ (delta) or the hypothesized effect size/standard error is 0.85. For the current study we have $\delta = 0.85(30/2)^{0.5} = 3.2$. Based on Cohen's tables for power of a statistical test this value provides a power estimate of 0.72 for $\alpha = 0.01$ and a power estimate of 0.89 at $\alpha = 0.05$.

In addition, when estimating the post hoc power of blood flow, we use the following method outlined in Keppel (1991) and referred to as Partial ω^2 or any ANOVA model:

$$\text{Partial } \omega^2 = \frac{(1)\text{variance of effect}}{\text{var. of effect} + \text{error var for effect}}$$

where (1) =

$$\frac{\text{dfeffect}[MS_{\text{effect}} - MS_{\text{error}} \text{ for effect}]}{[\text{levels of indep. variable}][\text{number of S}_{\text{s}} \text{ in expt.}]}$$

Substituting Partial ω^2 into the Pearson Hartley equation to estimate the power:

$$\text{Pearson Hartley } (\varphi) = \left[n \frac{\omega^2}{1-\omega^2}\right]^{1/2}$$

As a result, for blood flow measurements, we obtained the following power estimates.

Gender Not significant

Location of probe $\varphi = 3.7$ (df 1, 28) at 0.01 power is 1.00 and at 0.05 power is 1.0

Conditions (2 vs. 3) $\varphi = 3.4$ (df 1, 28) at 0.01 power is 0.98 and at 0.05 power is 1.0

Location x condition $\varphi = 3.4$ (df 1, 28) at 0.01 power is 0.55 and at 0.05 power is 0.76

DOCUMENT CONTROL DATA SHEET

1a. PERFORMING AGENCY DCIEM	2. SECURITY CLASSIFICATION UNCLASSIFIED Unlimited distribution -
1b. PUBLISHING AGENCY DCIEM	

3. TITLE

(U) Lack of gender difference in motion sickness induced by Coriolis cross-coupling

4. AUTHORS

Bob Cheung Kevin Hofer

5. DATE OF PUBLICATION	6. NO. OF PAGES
September 1 , 2003	10

7. DESCRIPTIVE NOTES

Published in Journal of Vestibular Research (12: 191-200)

8. SPONSORING/MONITORING/CONTRACTING/TASKING AGENCY
Sponsoring Agency:
Monitoring Agency:
Contracting Agency :
Tasking Agency:

9. ORIGINATORS DOCUMENT NO.	10. CONTRACT GRANT AND/OR PROJECT NO.	11. OTHER DOCUMENT NOS.
Scientific Literature SL 2002-035		

12. DOCUMENT RELEASABILITY

Unlimited distribution

13. DOCUMENT ANNOUNCEMENT

Unlimited announcement

14. ABSTRACT

(U) Throughout the history of motion sickness research, it has been reported that the incidence of motion sickness is higher in females than males. Women rate themselves as more likely to suffer from motion sickness on all major forms of commercial transport and in different motion situations, such as carnival devices and gymnastics. Most of these studies employed survey questionnaires and self-reporting. This study investigates if there is a gender difference in induced sickness by comparing their physiological response and subjective symptoms rating under controlled laboratory conditions. Thirty healthy subjects (14 males and 16 females) between the ages of 18-46 years old were exposed to the Coriolis cross-coupling stimulation induced by 120o/s yaw rotation and a simultaneous 45o pitch forward head movement in the sagittal plane every 14 seconds. Cutaneous blood flow, blood pressure, heart rate, respiration, skin temperature, and electrogastrogram were monitored throughout the trial. Graybiel's diagnostic criteria were used to assess sickness susceptibility before and after the Coriolis stimulation. Golding's scale was used to assess the severity of symptoms during the motion exposure. A significant ($p < 0.01$) increase of forearm and calf blood flow during cross-coupling stimulation was observed in both sexes. However, the subjective symptoms rating and objective cutaneous blood flow measurements indicated that there is no significant difference in sickness susceptibility to Coriolis cross-coupling stimulation between male and female. The electrogastrogram (EGG) data indicated that there is an increase in gastric activity during yaw rotation and head tilt. However, there is no correlation between the EGG activity and sickness symptoms reported. Our results indicated that there is no gender difference in susceptibility to acute Coriolis cross-coupling induced sickness. There is no clear indication that EGG activities obtained reflects the nauseogenic response to the aforementioned stimulus.

(U) Not available.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Gender; motion sickness susceptibility; Coriolis cross-coupling